NOTES ON THE CAVES OF FIJI, WITH SPECIAL REFERENCE TO LAU.

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A.—Introduction.

During a coral reef expedition undertaken in 1898 for Prof. A. Agassiz, of Harvard College, U.S.A., it was our fortune to examine a number of caves existing in the various raised coral atolls of the Fiji and Tonga groups.

These present many points of interest to geologist and naturalist alike. To the latter the scarlet prawns of the Vatu Leile caverns, the unique shell fish from Wangava, and other animal curiosities would furnish special attractions.

For the benefit of anyone wishing to further examine these caverns, we may mention the necessity of carrying ropes and magnesium wire.

For the purposes of cave photography, we would recommend a camera capable of being focussed within very short distances. We lost many pictures through inability to focus our camera on any object at distances less than seven feet.

The camera should also be fitted into a tin case provided with a closely fitting cover. The cover should be as deep as the case. This provision would ensure against accident in the case of an upset when crossing the numerous streams and lagoons, or when caught out in any of the heavy tropical rains.

Most plates are speedily ruined in the moist atmosphere of the tropical Pacific, owing to the growth on the films of a variety of fungi. They should be kept in a watertight box constructed of wood which has been soaked in oil. The box should be well painted, and provided with an overlapping lid, so as not to retain any water. Chloride of lime may also be carried in this box as a desiccator.

B.—The Caves of Viti Levu.

The only caves visited in this, the main island of the Fijis, were those contained in the elevated tertiary (?) limestone of Walu Bay and the coast between the Singatoké River and Thuvu (Nandrongá).

The limestones at the Singatoké dip seaward at about 15 to 20 degrees, and consist of soft and hard granular varieties much resembling some sandstones in hand specimens. The fossils are represented principally by pectinoid shells, echinoderm spines, foraminifera, and a very few fungoid corals. In one solitary instance an intercalated coral reef was found.

At Walu Bay the beds are in distinct layers, consisting of soft limestone bands, almost destitute of fossils, alternating with soft belts of coral reef, and reposing on brown and blue layers of volcanic mudstone, locally called " soapstone."

The cavern at the Singatoké lies about 5 miles from the river mouth, and possesses two approaches, one overlooking the sea in the face of a cliff some 300 feet high, and opening on to what at one time was the old channel of the Singatoké; the other entrance being on the flat land above the cliff. Both approaches are hidden by dense growths of palms, vandras, etc.

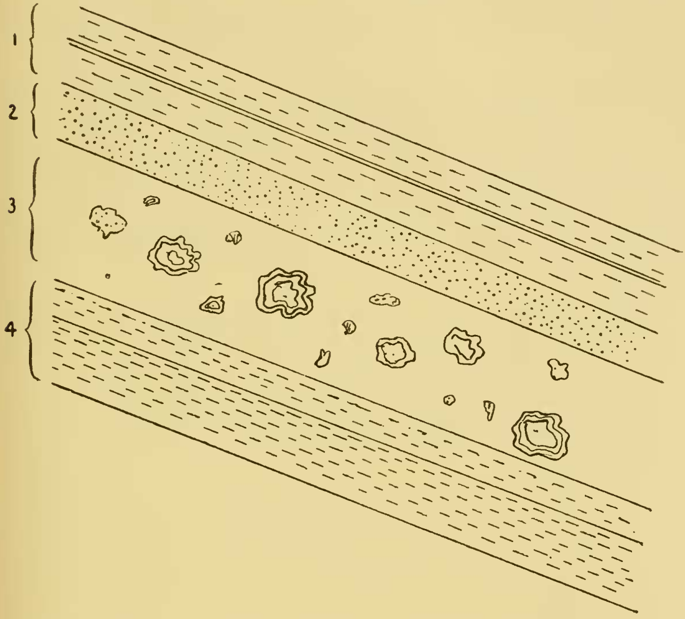

Fig. 1.—Section of Limestone containing Singatoke River Cavern.

1.—Dense red limestone.
2.—Calcareous mudstone.
3.—Coral band (reef).
4.—Red and yellow limestone (granular).

The cave, as far as we could explore it, was 250 yards in length (measured by chain), and very rough in nature. It consists of a series of lofty chambers connected by narrow tunnels, and tiny apertures through which it was at times very difficult to force a way.

The cavern maintains a fairly even dip of some 20°, crossing the bedding of the limestones at a very acute angle, so as to appear to follow their dip.

Some of the chambers were as much as 60 ft. in length, 30 ft. in width, and 50 ft. in height.

The section yielded by the cave is explained in the diagram (fig. 1).

The mouth of the cave is in a dense red limestone. Below this belts of fine calcareous mud are traversed, and beneath these a coral reef occurs, the contained corals belonging to varieties of Porites. Beneath these again mud and granular limestone occur.

This cave possesses stalactitic growths, though not in the marked degree in which they occur in other caves of the group. Thick mud deposits exist on the floor.

An interesting feature of this cave is the occurrence in thousands of the small Fiji bat, called by the natives beke beke. These could be seen covering the roof of the larger chambers, and progress through the narrow tunnels was much hindered by their attempts to pass us. White and apparently blind spiders are of frequent occurrence.

2.—*The Caves of Mata-ni-Vatu.*—Twenty-five miles from the mouth of the Singatoké two enormous cliffs of dolomite occur on the eastern bank of the stream. Their appearance is most imposing. The smaller one shows perpendicular walls to the river 400 to 600 ft. in height. Other parts of the cliffs are not quite so steep, but higher, rising 850 ft. out of the river. The larger cliff is very broken, and is over 1,200 ft. in height.

Caverns open out on these immense cliff faces. Our stay was too limited to admit of any attempt in the way of exploring these dangerous caves, since in certain cases long ropes are necessary to lower the climber from the crags above to the cavern entrances.

Natives who have seen some of the more easily approachable occurrences assert that they partake much of the nature of the Singatoké cave, but are larger, and the underground waters are inhabited by blind fish.

C.—THE CAVES OF LAU.

The Eastern, Windward, or Lau group lies some 150 miles east of the main island of Fiji (Viti Levu). The islands are disposed in a direction approximately meridional, and lie along the axis of a submarine anticline.

The group is about 300 miles in length, and is composed of numerous small islands. Many of these are composed of raised coral limestone. The elevation was not confined to one period, but consisted of uplifts alternating with periods of stable equilibrium, which latter are marked by "terraces" or horizontal extensions seawards of the coral growths, from the older mass of the island. So great has been the total uplift that the basal rocks on which the coral growths flourished may be frequently seen.

These basal rocks consist of huge masses of bedded limestone of moderate dip (15°-25°), differing altogether in lithological characters from the ordinary coral reef limestone.

Again volcanic mudstones form a common base, as also exceedingly decomposed volcanic conglomerates containing gasteropod shells allied to Trochus, Nerita, etc.

Mango, one of the group, may be briefly described as being typical of the raised limestone islands containing numerous caverns. The island is about 4 miles in diameter. It is approximately circular, and presents to the sea at almost all points precipices of raised coral limestone. These are 400 to 500 ft. in height. In former times an unbroken ring of limestone encircled the island, but its integrity has been destroyed by later volcanic outbursts. The perpendicular faces at times are succeeded by escarpments of about 45° slope, and appear to represent the original seaward slope of the atoll, for a raised atoll it appears to be, being hollow in the centre, after the similitude of volcanic craters.

Several traces of elevatory movements exist as more or less imperfect "terraces" or platforms of limestone. This limestone area is covered with great masses of vegetation.

An almost continuous barrier reef runs fairly parallel to the periphery of the island at distances varying from 150 to 300 yards. The coral growths are extremely luxuriant, both in the lagoon and on the seaward edge of the reef. For distances from the surface of 20 to 40 feet these coral growths are wonderfully varied.

The Caves.

1. *Mango.*—The limestone ring is riddled with caverns. Some of these exist in the form of narrow passages connected at times with the outside world by deep shaft-like holes, 100 feet or more in depth. These may be in rare cases varieties of sink or swallow-holes (dolinas).

A cavern in the north-eastern part of the island opens out in a great cliff face, and is about 200 ft. above sea level. It consists of several large apartments varying from 10 to 40 feet in length. Stalactitic, stalagmitic, and "shawl" growths are common.

Another cave in the north-east has two entrances, one in the form of a gigantic chimney 120 ft. in depth, the other occurring at the base of a cliff. This cavern consists of several systems of chambers branching out from each other, all very large, and needing the assistance of ropes in their exploration. Stalactitic growths are of frequent occurrence. The bottom chamber, 130 ft. below the cave mouth, is very spacious, and contains hundreds of swallows' nests, composed of mud.

To the north a very large swallow (?) hole occurs, 120 ft. in depth. This junctions below with a long tortuous channel running normally to the direction of the chimney, and conveys the drainage of the northern part of the island to the sea. This cave must be 700 yards in length.

Another large cave occurs in the north-west. The mouth is constricted, but affords entrance to a large hall 100 ft. long, 100 ft. wide, and some 30 ft. high, and possessed of a great wealth of stalactites and stalagmites.

Several branches take their respective points of departure from this antechamber, one being very large, exceedingly dirty, and dangerous for the uninitiated to explore. Large gaping holes occur throughout its 300 yards of length, and numerous subsidiary caverns ramify from the parent trunk. Other chambers of considerable size occur in a cliff to the south.

2. *Thithia.*—This island is almost a replica of Mango in every particular. Its caverns, however, partake more of the nature of lofty halls than long tunnels. Stalactites and stalagmites of great size occur in abundance. Immense deposits of bat guano cover the floors. In one cave a deposit 18 ft. deep was worked. The excessive moisture is said, however, to militate against the ready sale of these manures.

3. *Lakemba.*—A large cave occurs in one of the irregularly scattered patches of limestone existent on this island. The cavern is curvilinear in shape, not advancing directly into the hill, but turning back somewhat on itself from the start, so as to give the appearance, in plan, of a horseshoe with reduced convexity. It is a magnificent example of cave formation and worthy to rank among occurrences like Jenolan in point of size, though not in beauty. The floor, contrary to the usual type, is almost level, very wide, and covered with a thick deposit of mud. It is in the form of two large chambers, each about 300 yards in length, 50 ft. in width, and 50 ft. in height. A row of columns (stalactites) separates the caverns.

The roof is like that of a church, having a long central ridge, with two steeply inclined sides. Huge grey and white stalactites of irregular shape depend from the roof.

4. *Nghillanghillah.*—A marvellously beautiful little cave occurs in one of the islets forming the Nghillanghillah Group.* All of the raised coralline rocks composing the islets possess deep undercut lines of beach erosion. One is about 100 feet high, 20 yards in diameter at the base and cylindrico-conical in shape. It is merely a limestone shell, the central portion being absent. The internal contour is approximately a reflex of the exterior. Tiny entrances occur in the undercut portions, through which the sea has free

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* A. Agassiz, Bull. Mus. Comp. Zoology, Harvard Coll. Vol. xxxiii. p. 91.

access to the cave, the floor of which is occupied by about 5 feet of water. The roof is about 75 feet above the floor (fig. 2).

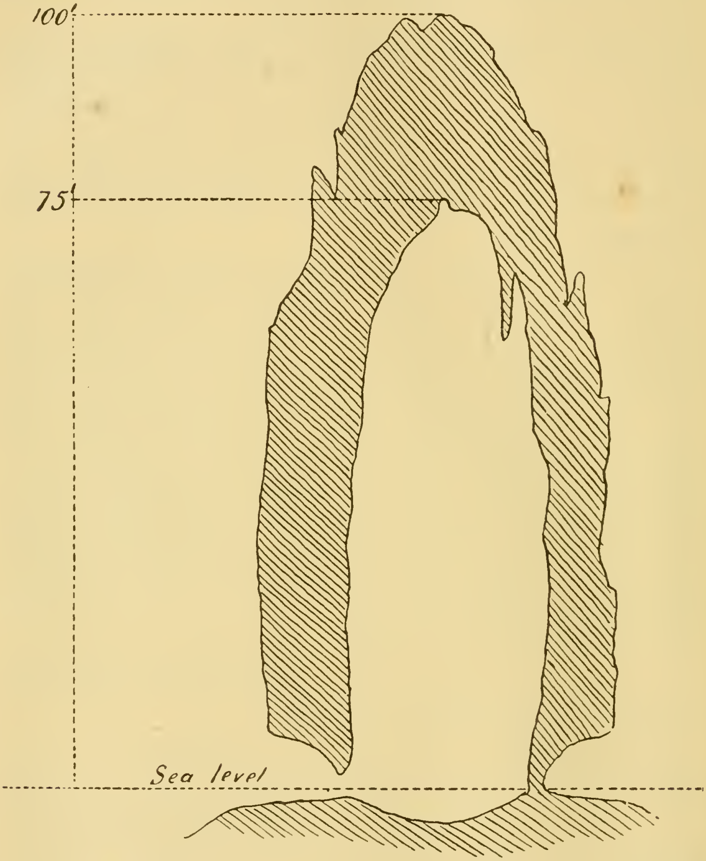

Fig. 2.—Sketch Section of Nghillanghillah Cave.

5. *Bai Vatu.*—The mass of raised limestone known by this name is separated from Nghillanghillah by a deep though narrow channel. On the western and eastern sides huge cliffs occur, 400 feet in height. Many caverns are said to exist in this area.

One, however, only was seen by us, the others being difficult of approach. The occurrence was similar to the caves of Thithia.

6. *Vatu Leile.*—This island contains caverns on its west coast, partly submarine in habit. They occur at the base of large cliffs, and are of very irregular shape, having the form of large chambers communicating with the sea (lagoon) by means of submarine conduits. They are approachable from the land side by openings in the limestone shell encasing them. The cave waters contain multitudes of speckled scarlet prawns of large size. This is a unique occurrence.

Numerous caves are reported to exist in the raised limestone of Katavanga, Naitamba, Gamia, Tuvuthá, Vanua Vatu, the Yangasa and Yasawa clusters. These are said to be similar in character to those of Mango or Thithia.

D.—The Crevasses in the Submarine Reef-platforms.

Some of the platforms fringing the various islands of the Lau Group are marvellously cut up by networks of channels. On passing over them at high tide in a small boat the general flat of the reef is seen to be broken repeatedly by chasms and lenticularly-shaped chambers.

At Vatu Vara one of these cracks has perpendicular walls, is about 20 feet across, and is at least 200 feet deep. This great depth was not continued throughout the reef to the sea, but shallows away to nothing at the reef edge.

At a depth it appeared to open out into chamber form.*

At Kambara the whole reef flat is broken up by a series of deep cracks.

The walls of these crevasses are composed of luxuriant growths of Madrepores, Porites, Pocillopora, etc.

Mango furnishes similar sights, though on a much smaller scale.

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* It is quite easy to see objects at a depth of 100-120 feet in these clear seas, and this too without the aid of water glasses.

Every island navigator is familiar with the deep clefts in the fringing reefs of the shallow Somo Somo Strait at Taviuni.

A characteristic feature is the arched appearance they frequently present to the sky, having narrow openings at water level, and a series of wider anastomosing canals below.

Now, in Vatu Leile, as explained in a previous paragraph, we have caves partly under and partly above water, the whole appearance being that of a series of chambers with a few narrow passages opening upwards and outwards to the sky.

Near Tuanuku, in the Vavau Group (Tonga), a beautiful cave exists in the raised limestone. This also is half-submerged, yet of such a size that we sailed a cutter, with mast up, right into the cavern. The highest part of this chamber must have been 70 feet above water level, and the water inside the cavern was of equal depth. This chamber was connected with others by passages, and opened to the sky by a small hole.

It seems that here we have a condition of things attainable by suddenly raising the present fringing reefs of Kambara and Vatu Vara, so as to leave the crevasses and chambers half submerged.

E.—1. Description of Cave-Formation generally.

Acidulated water (deriving its acidity from decaying vegetation, &c.) trickling over limestone, attacks the rock mass, carrying it away, little by little, in solution. In this way, by attacking the rock along the joint-planes, swallow- and sink-holes are formed in the limestone mass. These, after a time, may become united at a depth through the continued action of the percolating waters. Eventually a subterranean watercourse is formed, and the shape of the excavation is that of a series of chambers united by tortuous passages.

When a cave has been excavated, the water still eats into the the stone, and other sink-holes being formed below its level, the old stream bed is deserted in favour of a newer and lower one.

The process of refilling now sets in at the upper level.

Water trickling down and from the roof allows of an infinitesimal amount of evaporation. This is, however, sufficient to permit of a tiny deposit of carbonate of lime on the roof or floor. These deposits, as time goes on, take on the form so common in cave scenery, such as stalactitic, stalagmitic and shawl-like growths.

2. *Origin of the Viti Levu Caves.*—These are very probably due to agencies which determine cave-formations generally, as described in the preceding paragraph.

For the limestones in which they occur both at the mouth of the Singatoké River and 25 miles higher up the stream show bedding planes as pronounced as those of the Hawkesbury sandstone, and, with the exception of a single intercalated coral reef and a few scattered fragments, are utterly devoid of coral growths. They are also of sandy nature, after the fashion of compacted braches, and are thus composed of waste sheets. The cave also in the limestone at the Singatoké mouth follows the bedding of the strata for long distances, and contains *very thick* deposits of mud on the floor.

These observations point to formation subsequent to the limestone deposition, although it is possible that the initial stages were determined by submarine agencies, post-dating the formation of the strata.

3. *Origin of Lau Caves*.—These appear to be moulded on lines totally different to those obtaining at Viti Levu. Whereas the majority of caves owe their existence to hypogene agencies, it seems more feasible to refer the origin of the typical Lau caverns to submarine action modified to minor extent only by hypogene influences.

It may not be generally known that the greater number of modern "reefs," such as those of Fiji, are composed of coralline débris, foraminiferal tests, echinodèrms, mollusc shells and vast quantities of calcareous algæ (such as Halimedæ and Nullipores). Calcareous matter is also deposited between the tiny interstices of these fragments until the mass assumes a homogeneous appearance.

On the seaward edge of these, however, luxuriant coral and nullipore growths occur. It is also very common in the lagoons to see huge isolated masses of growing coral. As these masses expand, there is a tendency for the isolated patches to coalesce by fusion of the growing walls. Withal, however, channels are frequently left between the clumps, probably to permit of circulating waters conveying nutriment to all. The coalescence or fusion of the expanding growths is most marked towards the sea level, the tendency being to form arches overhead and to leave a series of anastomosing canals below, broadening here and there into chambers. Nullipores also help considerably in the work of solidifying the mass and the closing in of the overhead growths.

The appearance of the structure just described, viewed from a short distance, is that of a solid reef-platform flush with the sea level.

The study of such fringing reefs as those of Taviuni (Somo Somo Strait), Mango, Vatu Vara, Lakemba and Kambara will illustrate the foregoing remarks.

Prof. David, of Sydney University, and Mr. C. Hedley,* of the Australian Museum, mention the arching over of the submarine channels of Funafuti by coral, nullipore and allied growths.

On the Tonga Tabu coast, numerous "blow-holes" occur in the reefs. These consist of long submarine conduits in the fringing coralline limestone mass, opening out to the sky by constricted orifices.† Into the wide mouths of these tunnels the sea dashes, and becoming confined as the way becomes narrower, is dashed into the air as spray by the on-rushing water behind.

Prof. David mentions similar, though smaller, occurrences at Funafuti.

At Wangava, in southern Lau, a central salt lagoon exists, shut in from the sea on all sides by high limestone cliffs. The tide is said to rise in the lagoon, thus showing its connection with the outer sea by a long, submarine passage.

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* C. Hedley, Natural Science, xii., 1898, p. 177.

† For this information we are indebted to Mr. J. Martin of Auckland.

At Namuka, in the Tongan Group, one of us witnessed a similar phenomenon.

It seems very probable that the caves of Vatu Leile and Vavau have been formed by processes such as those just described, and that they mark stages in the process of reef-making.

At Vatu Leile there are unmistakable signs of recent upheavals, the whole series of elevations (5 in number) being of so recent a date that the line of beach erosion on the cliff which marks the position of stable equilibrium before the elevatory influences came into play has not yet been obliterated.

Again, above the caves a thin crust of limestone occurs, marking the old reef-platform. Where this old platform ends against the cliff another line of beach erosion exists, and that nearly perfect. It will thus be seen that these large half-marine, half-aerial chambers must have been excavated while the line of beach erosion suffered but very slight alteration, if we assume that æolian agencies have been the prime factors in their formation.

At Vavau we have a very similar state of things. Here the uplifts are 3 or 4 in number. It is, however, possible that the lines of beach erosion may suggest another method of formation for these caverns.

In Mango and Thithia the broader outlines of the caverns seem to have been determined by submarine agencies.

It is impossible to ascertain the exact condition of the cave-walls, as they existed beneath the sea, since secondary deposits of calcareous material have so covered them as to obscure their original shape.

Stalactites, stalagmites and shawl-like growths do not appear to imply great periods of time, as may be seen by an examination of the most recent of the raised lines of beach erosion on Vatu Leile. This is in places where the cliff overhangs almost entirely obliterated by stalactitic deposits, while in other portions of the island the line of beach erosion is almost as intact as when it rose from the sea.

To summarise, then, it seems probable that :—

(*a*) The limestone fringing the shores of Viti Levu is mostly of stratified and shelly character, with rarely intercalated reefs.

(One such reef only was observed by us at the Singatoké River, and several at Walu Bay and Tamavua.*)

The caves of Viti Levu exist in rocks possessing most pronounced dips, varying from 10° to 20° in amount.

(β) The Lau limestone is of later origin than the bedded Viti Levu deposits, as shown at Bai Vatu where coral reefs form thin crusts only on thick bedded masses of limestone indistinguishable in lithological characteristics from those at the mouth of the Singatoké River.

The Lau caves occur in compact, hard limestone formed of corals, shells and calcareous algæ and exhibiting no bedding planes.

(γ) The Viti Levu caves appear to possess an origin similar to that of caves existing in continental areas, where æolian agencies have been the designers.

(δ) The Lau caves appear to have been determined by coral growths and submarine action, and owe their stalactitic growths to influences acting subsequently to their elevation above sea level.

F.—Description of Access to Caves.

Frequently the entrances to the caves occur in the faces of the cliffs as apertures, invisible, except on close inspection, by reason of the rough nature of the rock and the mantle of vines and shrubs that invariably accompany the raised limestone areas. Others again are approachable only by descending one of the deep cracks that intersect the limestone in all directions.

It is impossible for one unaccustomed to similar sights to appreciate either the roughness of the raised reefs† or the dense growths that cover them.

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* J. S. Gardiner, Proc. Cambridge Phil. Soc. Vol. ix. 1898, p. 425.

† A. Agassiz, Bull. Mus. Comp. Zool. Harvard Coll. Vol. xxxiii. Pl. 98.

People, unless good climbers, are frequently unable to cross the limestone belts that surround the island, owing to the cracks or crevasses present, which are at times as much as 100 to 150 feet deep, although not more than 10 or 12 feet wide.

The vegetation is even more wonderful, both by reason of its luxuriance and its method of securing itself to the rock.

Although almost devoid of soil, the raised coral rock supports a dense forest growth that cuts off the direct rays of the sun from the ground beneath. The trees swarm down even almost perpendicular limestone scarps. Supplied with the power of expanding their roots in tubercle fashion, they make capital out of every little irregularity of surface. At each hole in the honeycombed rock they stop to fill up the cavity, then advance ivy-like roots to the next depression.

The vandra (screw pine) develops spiny aerial roots which depend from the rocks in a scalariform manner.

Perhaps the most wonderful of all these growths, however, are the fig trees and the various members of the convolvulus tribe.

In some of the islands the only method of approach to the caves is by descending the long fig tree roots.

G.—Caves as Dwellings and Fortresses.

The inhabitants of Lau until quite recently lived an almost Ishmaelite existence. The various island tribes fought desperately with each other for supremacy, and even the people belonging to any given island were divided among themselves.

On such a small area as Mango as many as three or four distinct cliques existed, each antagonistic to the other. The highest and most inaccessible points, which formed natural fortresses, were chosen as watch towers, from which the sentinels estimated daily their chances of conquering or being conquered.*

In almost every instance which came under our observation, the excessively rough limestone cliffs formed these points of vantage. Near at hand were the caves we have described.

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* For this information we are indebted to the Hon. J. M. Borron, of Mango.

Almost invariably the isolated and almost inaccessible limestone plateaux contained large heaps of shells of various kinds, the remnants of shellfish brought from the seashore for food.

The rough nature of the limestone and the dense covering of vegetation made it impossible for a surprise to be sprung upon the concealed township, as the sentinels could give timely warning.

A very interesting feature about the caves existing in the close neighbourhood of these shell mounds is the existence of the numerous "Bai Valu" or fighting walls, seen so frequently in the various Lau islands. The caves often open out into cañons. The mouths of these defiles are set with walls of stone, breast high. Every approach is guarded with them, and outlying walls support these in turn. We have seen as many as a dozen of these walls belonging to a single cavern. In cases where caves exist in the cliff faces, the defiles below are accompanied by these walls (*e.g.*, Mango and Bai Vatu). At Bai Vatu some of the walls are very lengthy, and overlook steep sloping ground.

We were informed by the Hon. J. M. Borron, Mr. F. Beddoes, of Mango, and others, that these caves were used as retreats for the women in the olden days in times of war, while the warriors defended the walls. On the other hand, Dr. B. G. Corney, chief medical officer of Fiji, says that to the best of his knowledge they were used simply as burial places. In one cave one of us (B. Sawyer) discovered three skeletons laid side by side. In another chamber we discovered relics of former feasts. Some of these consist of large brain corals, having the original flat surfaces worn hollow by scraping kava on them. These are known as "yangona scrapers."

The existence of these caves in rough country, the concealment of their entrances, the numbers of the "Bai Valu" closing every way of approach to the more inaccessible ones, the existence of "yangona scrapers," etc., the discoveries of skeletons in the cave recesses, and the proximity of the underground chambers to the large shell-mounds of the limestone plateau seem to point both to their habitation in former times by natives in time of war, and to their use as burial places.